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NUTRITION AND PHYSICAL PERFORMANCE IN MILITARY ENVIRONMENTS

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NUTRITION AND PHYSICAL PERFORMANCE IN MILITARY ENVIRONMENTS

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Summary

This report is a review of research findings concerning nutritional aspects of physical performance with direct relevance to the operational requirements of military personnel.

The body's stores of carbohydrates are limited compared to those of the other energy stores. Unfortunately, it is these limited carbohydrate stores on which muscle is most dependent for fuel as the intensity of physical exercise increases. When the intramuscular stores of carbohydrates, in the form of glycogen, are depleted subsequent exercise performance is impaired. There is direct evidence that muscle glylcogen stores of military personnel are markedly depleted at the end of combat field trials. The consumption of >450 g of carbohydrate per day should facilitate adequate glycogen resynthesis. There is experimental evidence that adaptation to a calorie-dense, fat-rich, i.e carbohydrate-poor, diet may be possible although the time course and extent of adaptation must be clarified before such a diet can be applied.

There is no consistent evidence to suggest that the capacity to perform physical exercise would be enhanced by the addition of micronutrients to rations. Futher research may be warranted, however, by the findings that amino acids such as l-tryptophan and tyrosine have been demonstrated to enhance cognitive performance under conditions of environmental stress.

Calorie restriction causing body weight loss of up to about 10% will not cause drastic performance impairments if dehydration, ketosis, and hypoglycemia can be avoided. Lightweight daily rations containing 2000 kcal are therefore feasible for units for whom a reduced foodpack weight and volume would be advantageous.

The environmental stress of heat or altitude causes an anorexia which can result in insufficient energy and/or carbohydrate intake to maintain optimal physical performance. Cold environments are usually associated with an increased energy consumption, probably because of the increased caloric cost of working in rotective clothing and with specialized equipment. The implications of most environmental stresses are that the relative physiological demands of a given task are increased. In all likelihood the energy cost and the dependence on carbohydrates for that energy are also increased.

1.0 Introduction

The physical performance demands of military personnel range widely depending on the trade of the individual soldier, the mission of a unit, the environment in which the mission is to be accomplished, and whether the scenario is performed during peacetime, training, or actual conflict. These physical demands can be rather sedentary in nature, similar to those encountered in the civilian sector, in which case national nutritional guidelines for the quantity and quality of energy consumption should suffice for feeding military personnel. Military activities can, however, result in energy demands which are far greater than those experienced in civilian life. Mean daily energy expenditure during military field trials has been reported to range as high as 10,000 kcal in some cases (1, 2). Moreover, activities which usually demand minimal energy expenditure can become quite demanding when they are performed in special environments to which the soldier may be exposed, e.g. heat, cold, protective clothing. The ability to adequately fuel these energy demands, to avoid fuel exhaustion and the associated performance impairments, and thus to enhance performance via appropriate energy consumption (i.e. food intake) could be critical in the life or death situations in which military personnel are trained to operate.

Since WWII several reviews of the special nutritional needs of the military have been published and a detailed annotated bibliography was prepared by Buskirk (3) for the American Committee on Military Nutrition Research, Food and Nutrition Board, of the National Research Council Commission on Life Sciences. More recently, this same committee published the proceedings of a unique workshop (4) which provides both a detailed historical perspective and an up-to-date review of the effects of deviations from recommended daily nutritional allowances on physical performance and physiological homeostasis in controlled laboratory experiments as well as in military field trials.

2.0 Selective macronutrient utilisation and exercise intensity

Newsholme and Leech (5) calculated the duration of time during which an average sized man (65 kg body weight, 12% body fat) could either run at a marathon pace ($\approx 84 kJ \cdot min^{-1}$) or walk ($\approx 6.4 km \cdot h^{-1}, 21.7 kJ \cdot min^{-1}$) using only one of the body's fuel stores (Table 1).

Table 1. Fuel reserves in average man.

Fuel store	Reserve g	Reserve kJ	Fuel sufficient for Walking *days*	Fuel sufficient for Running *min*
Adipose tissue	9000	337000	10.8	4018
Liver glycogen	90	1500	0.05	18
Muscle glycogen	350	6000	0.20	71
Circulating glucose	20	320	0.01	4
Body protein	8800	150000	4.8	1800

from Newsholme & Leech, 1983

In contrast with these theoretical calculations, the transduction of the chemical

energy in these fuel supplies into mechanical work by muscle tissue depends on simultaneous contributions by all of the fuel reserves. The energy demands of sedentary activities are covered approximately equally by the catabolism of fat and carbohydrate; the contribution of carbohydrates increases as the intensity of exercise increases until almost the entire energy demand of supramaximal exercise of a 30-60 second duration is met by carbohydrate metabolism. Although protein metabolism probably contributes significantly more to energy metabolism than previously believed (6), Table 1 demonstrates that it is unlikely that the body's stores of protein and/or fat would be depleted to the extent that the capacity to transduce energy to the working muscles would be impaired.

The final report of NATO AC/243(Panel VIII) Research Study Group 4 on Physical Fitness identified aerobic capacity, muscular strength and muscular endurance as important components of military occupational requirements (7). Prolonged forced marches, lifting and loading (e.g. artillery shells or sandbags), and hand-to-hand combat exemplify activities which correspond to each of the fitness components mentioned above. Such activities span a wide range of relative intensities of physical exertion from the submaximal activities which may be performed for hours, to activities which demand short bursts of explosive power for only a few seconds. With regard to specific macronutrients, the availability of carbohydrates has been shown to have direct implications for the kind of physical performance referred to above.

3.0 Muscle glycogen and exercise performance.

Recent review papers describe the history of laboratory studies, beginning in Scandinavia in the 1930's, which demonstrated that a carbohydrate-rich diet increases the length of time exercise intensities of 70-85% of maximal aerobic power (VO_2max) can be maintained, and that this is a direct function of the concentration of glycogen in the exercising muscles before exercise. Later studies demonstrated that both muscle and liver glycogen concentrations were directly influenced by the amount of consumed dietary carbohydrate, and that both glycogen levels and endurance exercise performance covaried with changes in the absolute amount of ingested carbohdyrates (8,9).

More recent studies have demonstrated that the depletion of glycogen from skeletal muscle is associated with impairments in muscular strength and in the ability to perform short term, high intensity exercise lasting less than one minute (10-13).

Physical performance in a military scenario contrasts with the laboratory studies described above in that the former usually demands several days of physical activity as opposed to a single bout of exercise. Costill et al. (14) investigated the potential implications of dietary carbohydrate ingestion on three consecutive days of hard exercise. The exercise was commenced each day with a progressively lower muscle glycogen level when a relatively carbohydrate-poor diet (i.e. 40% of total calories) was consumed. It is reasonable to assume that exercise performance would be affected in a similar manner. When the same subjects consumed a eucaloric high carbohydrate diet (70%), muscle glycogen levels were almost completely restored to normal during the 24 h between exercise bouts.

3.1 Muscle glycogen changes during military activities

Do skeletal muscle glycogen levels become depleted in military personnel to the extent that exercise performance may become compromised? Very few studies have been carried out during actual military field trials because of the invasive nature of the biopsy procedure used to obtain a skeletal muscle tissue sample. In Swedish (15) and Canadian commandos (I. Jacobs, personal

communication, November 1987), glycogen levels in the thigh musculature after 4-5 days of field trials were reported to be less than 50% of the pre-trial values. It is interesting to note that these decreases in glycogen occurred even when daily nutritional energy intake amounted to as much as 3700 kcal, of which carbohydrates comprised 64% or 580 g (15). This attests to the high energy demand, i.e. the intensity, of the activities performed in the field. Based on the direct relationship between changes in glycogen levels and the extent of the impairment of endurance performance, it was suggested that the glycogen levels observed in military personnel at the end of the field trials could be expected to be associated with a 30-40% decrement in endurance if the soldiers had been subsequently required to perform relatively high intensity tasks over a prolonged period of time. A concomitant 10-25% decrement in muscular strength or explosive power can also be expected with these decreases in muscle glycogen concentrations (10-13).

Self-pacing, or the work intensity at which soldiers choose to work may also be affected by the availability of glycogen in the exercising muscles. This was suggested in a study carried out at altitude (16), in which a group of soldiers whose daily energy consumption included 404 g carbohydrate per day, covered significantly greater distances during their daily runs than did a control group consuming only 187 g carbohydrate per day. Further support comes from a study by Saltin (17) on two teams of soccer players, one of which exercised hard to become glycogen depleted the day before an experimental game. Film analyses of the players' movements during the game showed that the glycogen depleted team covered 20% less distance during the game, and that they sprinted only 15% of the time they were in motion, compared to 24% for the control team.

3.2 Glycogen strategies.

The most reasonable approach to avoid the performance impairments associated with glycogen depletion is to attempt to a) delay the onset of a glycogen exhausted state by commencing exercise with relatively high intramuscular stores; b) restore glycogen stores as rapidly as possible after exercise is completed so that the soldier is physiologically prepared for a subsequent exercise bout; c) provide an alternative source to fuel muscle contraction.

Costill et al. (18) demonstrated that after exhaustive exercise in 72 kg male runners, glycogen levels could be almost completely restored to normal levels within 24 h when the subjects consumed 3700 kcal of which 70% (648 g) were carbohydrates. The rate of glycogen repletion was equally high when the carbohydrates were consumed over either two meals or seven meals during the day. This study also indicated that the rate of replenishment of glycogen was similar if the consumed carbohydrate was in a simple or complex sugar form.

Recent studies have suggested another strategy for delaying the onset of glycogen depletion by presenting the musculature with alternative fuels. The use of methyl-xanthines, such as caffeine, will increase the concentration of circulating free fatty acids. Skeletal muscle will consequently use more circulating fat as an energy source and thereby decrease the utilization of glycogen (19). Recent studies have also demonstrated that carbohydrates other than glycogen can be oxidized during exercise. For example, subjects in one study were able to maintain an exercise intensity of 71% VO_2max for 33% longer when they drank a glucose solution during exercise (4.02 h) than when they exercised in the control condition (3.02 h). The authors interpreted their results as indicating that when fed carbohydrates during exercise, oxidation of carbohydrates other than muscle glycogen may result in the postponement of fatigue during strenuous exercise (20). Although there is recent strong evidence that the ingestion of either liquid

or solid carbohydrates just before and/or during exercise can be beneficial (21), there are several studies showing no performance ehancement (22,23).

4.0 Adaptations to Fat-rich Diets

Although the relationship between exercise performance and carbohydrate consumption described above is well established, there are several potential logistical advantages to a high proportion of fat in field rations because of the high calorie density in fat relative to carbohydrates. The associated light weight, and compactness of such rations, relative to eucaloric mixed or carbohydrate-rich rations were attractive to researchers during WWII. An attempt to evaluate such a ration was made by Kark et al (24), who provided a ration of pemmican (70% fat, 30% protein) and tea to a platoon during a physically demanding winter field trial. The results were disastrous, in that the platoon was rendered operationally useless within three days, suffering from ketoacidosis and dehydration. It is difficult to evaluate, however, if these results can be directly attributed to the lack of nutritional carbohydrate, or are rather an effect of caloric deficiency and/or dehydration.

Contrasting with the above, Phinney et al. (25) performed a well controlled laboratory study which examined the effects of 4 weeks of a carbohydrate-poor diet on subsequent exercise performance. Care was taken during this study to ensure that the recommended daily allowances for vitamins and minerals were consumed, and that the total caloric consumption was eucaloric relative to the control diet. The design of this study differs from those described earlier in this report in that the period of adaptation to the ketogenic diet was at least four times longer in this study. Their results suggest that endurance exercise performance may not be impaired after a prolonged period of adaptation to a fat and protein-rich diet. In their study, circulating glucose and muscle glycogen concentrations were normal after four weeks of this carbohydrate-poor diet, and the subjects were able to exercise for a similar duration during the experimental (151 min) and control (147 min) exercise bouts. The subjects in this study were very fit cyclists who may have a favorable training-induced disposition for high rates of gluconeogenesis. Whether or not the same findings would be applicable to less fit military personnel remains to be investigated. There are obvious implications however, for long-range patrols and/or covert observations units which may be required to be nutritionally self-sufficient for several weeks. A 50% reduction in the weight of rations to be carried and stored is significant not only for logistical reasons, but also because energy expended just to carry the rations would also be proportionately reduced.

5.0 Micronutrients and exercise performance

Present knowledge about vitamin status and exercise performance has been recently reviewed by van der Beek (26,27). These reviews indicate that supplementation of either fat or water soluble vitamin intake, over and above that consumed according to normal national nutritional guidelines, will not enhance physical performance. In fact excessive consumption of both classes of vitamins may result in toxicity. In contrast, vitamin intake amounting to only 35% of RDA may result if attention is not paid to consuming a balanced diet (27). Such deficiencies lead to a marginal vitamin B_1, B_2, B_6, and C status within 4-6 weeks, and van der Beek has observed concomitant impairments in indicators of endurance exercise performance (27).

Tyrosine is an amino acid precursor of catecholamine neurotransmitters contained in animal protein foods. The effects of acute ingestion of 100 mg/kg of tyrosine were investigated in a recent double blind study with male military

volunteers exposed to a combination of mild altitude and cold stresses (28). Tyrosine administration reduced the adverse effects of these stressors on performance tests of complex information processing, vigilance and reaction time and on mood states. Subjective feelings of cold stress, discomfort and headache were also reduced with the experimental treatment.

The use of another amino acid, l-tryptophan, has been tested in an attempt to increase the amount of sleep in personnel being transported across time zones and thereby minimize the negative effects of "jet lag". The results suggest that ingestion of l-tryptophan may promote sleep without the performance and responsivity impairments usually associated with sedating agents (29).

In neither of these latter two studies was physical exercise performance evaluated but the potential benefit indicated by the positive treatment effects warrants further research.

6.0 Caloric Restriction

Survival situations, emergencies, supply line breaks are all examples of military scenarios associated with caloric restriction. Some special military units may restrict their nutrition voluntarily to lower the loads to be carried on covert missions, long range patrols, etc. Early studies indicated that operational performance can apparently be maintained for at least two weeks with mean daily energy consumption of 1800-1900 kcal, even when mean daily energy expenditure was estimated at 3500 kcal (30). In this regard, it should be mentioned that VO_2max has been reported in some studies to decrease by as much as 20% when energy intake is restricted to 400 kcal/day for up to ten days; other studies have reported no effect on VO_2max (31). In such studies it is difficult to partition out the effects of calorie restriction from the confounding effects of other stressors such as dehydration, sleep deprivation, and other non-specific stressors.

Whether or not the measurement of VO_2max is even a valid indicator of endurance performance of a soldier is debatable and this points to the main problem with past studies: the quantification of physical performance after caloric restriction. The extent of the negative caloric balance, and the associated performance impairments, will vary greatly, depending on the energy demand of the specific mission. In an excellent review of this topic, Grande (31) recently concluded that in the presence of sufficient nutritional consumption to ensure adequate vitamin status and to avoid ketosis, dehydration and hypoglycemia, performance (measured as VO_2max and handgrip strength) was satisfactory during conditions of moderate energy expenditure up to a weight loss of 10% of the control body weight. Grande also emphasized that the experiments he reported were performed with fit young male subjects, and that tolerance to semistarvation may be different in less fit and older individuals.

A lightweight daily ration containing 2000 kcal was recently tested as the sole source of food for 30 consecutive days during a field trial with American Special Forces soldiers (32). Although weight loss in these soldiers (6% of original body weight) was significantly greater than in the control group consuming normal rations (2% of body weight), the effect on physical performance was equivocal. Although some indices of muscular strength and endurance, and VO_2max were impaired to a greater extent in the energy restricted group, other performance tests suggested that the effects are similar to the impairments demonstrated by the control group consuming normal rations (32). Such performance impairments are therfore difficult to attribute to nutritional insufficiencies without further basic research.

7.0 Environmental factors

Environmental stress, by definition, adds to the demands placed on physiological organ systems to perform a specific task or amount of work. Regarding exercise performance the effect is typically to magnify the physiological responses to exercise. The net result is that fatigue occurs earlier or the rate of work output must be decreased in order to avoid fatigue. Therefore any nutritional manipulations or strategies which under normal conditions ameliorate the ability to meet this increased relative exercise intensity will probably be beneficial in the face of environmental stress.

Much environmental physiological research was carried out during and immediately after WWII, but since that time technological advances have been very successful in the development of means to protect personnel from adverse environments while maintaining or improving operational efficiency. Nutritional considerations described below may prove beneficial as an adjunct or back-up to technology.

7.1 Altitude.

Almost 50 years ago it was estimated that a high carbohydrate diet would significantly increase the elevation than an unacclimatized man could tolerate while breathing ambient air (33). It was calculated than the increase would amount to 305-608 m above the normal 4573 m level. These calculations were based on the knowledge that more oxygen is needed to burn fat than to burn sugar to carbon dioxide and water. Mitchell and Edman (34) reviewed several studies showing a beneficial effect of high carbohydrate intake on "...mental efficiency, neuromuscular coordination, the capacity for muscular work, the field of peripheral vision, and the acuity of vision in dim light. It (carbohydrates) defers syncope for a longer time and decreases the severity of the symptoms of decompression sickness." These effects were most marked in comparision with diets high in protein content and less marked in comparison with normal uncontrolled diets. Mitchell and Edman (34) also indicate that these effects were observed with subjects breathing ambient air at altitude and that breathing oxygen may reduce the extent of the benefit.

Anorexia is associated with a sudden move to altitude, as is well demonstrated in recent reports with military personnel moved to 2194 m (35) and 4100 m (16). Even at the relatively mild altitude in the former investigation, energy consumption over a ten day period was only 67% of the calories required for energy balance in spite of the ad libitum access to 1200 kcal per meal. The resultant 3% body weight loss consisted predominantly of fat and was associated with a significant 5% decrease in VO_2max. More marked impairments of endurance performance with increasing time at altitude could be expected because of the markedly reduced daily carbohydrate intake (260 g/day) which would decrease skeletal muscle glycogen stores. The latter study (16) suggested that the addition of 5-7 beverage packets per person per day, each consisting of 35-40 g of carbohydrate, would not only reduce the daily energy deficit but may also benefit the ability to perform endurance exercise while at altitude.

These results confirm the work of Consolazio et al. (36) which demonstrated enhanced exercise performance and reduced clinical symptomology in military personnel who consumed a carbohydrate-rich liquid diet compared to a control group during rapid ascent to altitude.

7.2 Cold ambient temperature

Nude resting humans respond to the increased body heat loss in the cold by increasing heat production, i.e. metabolic rate, by five to sevenfold (37,38).

The caloric cost of performing light exercise in cold air is also increased unless the cost of the exercise is greater than about five times the normal resting metabolic rate (38-40). This increased caloric cost is probably accompanied by a greater combustion of carbohydrates (i.e. glycogen) to perform a given amount of work in the cold (41). Harder exercise provides enough endogenous heat production to compensate for the increased heat loss in the cold (38-41).

Although protective clothing minimizes the likelihood that military personnel will be physiologically cold stressed for prolonged periods of time, it has been repeatedly observed that nutritional energy consumption is increased in military personnel in the cold. This is consistent with Brobeck's (42) speculation that food intake was a dependent variable involved in temperature regulation, demonstrated by the fact that "...animals eat to keep warm, and stop eating to prevent hyperthermia." Empirical support for such an inverse linear relationship between voluntary caloric intake and local temperature was demonstrated (43) for North American soldiers living at temperatures between approximately -34 °C and 33 °C; the associated daily caloric intake ranged from 3100 to 4900 kcal, respectively.

Several studies subsequently reported that the increased caloric intake could not be directly attributed to increases in energy requirements because of cold, per se (44,45). These studies agree that any extra energy requirements in a cold environment are probably because of the extra heavy clothing which imposes a resistance to body movement and decreases mechanical efficiency, and heavy foot-gear which results in an increase in energy expenditure.

A review of available military reports reveals that energy balance during heavy exertion in cold field environments could require a daily energy intake of as much as 4200-4500 kcal (46,47). This corresponds to about 45-63 kcal/kg per day for light to heavy work; additional calories would have to be provided to account for waste.

A detailed description of a mid-winter 78 day, 5440 km motorized patrol of the Arctic reported that nutritional and physical performance deficiencies were not observed during or after the patrol with the provision and consumption of the nutrients described in Table 2 (48).

Table 2. Mean daily values for nutrients provided and consumed during Exercise "Musk Ox", February-May 1945 (48).

Nutrient	Provided	Consumed
Energy, kcal	5190	4400
Protein, g	145	120
Carbohydrate, g	575	520
Fat, g	225	190
Vitamin A, IU	6100	4900
Thiamine, mg	2.8	2.2
Riboflavin, mg	3.5	2.8
Niacin, mg	31	26
Vitamin C, mg	80	50

Fluid consumption during this patrol was about 1.2 l/day, ranging from 0.7 to

3.4 l, although most members of the patrol complained of being frequently thirsty and not having enough time to melt snow for sufficient water. A more recent study of subjects living at -23 °C for five days in an environmental chamber demonstrated that consumption of 3 l of water per day was sufficient to maintain hydration, but even 1.5 l per day avoided impairments of endurance exercise performance in spite of a 3.5% body weight loss (49).

A recent human study has suggested that pharmacological manipulations may enhance cold tolerance by increasing the availability of fuels to the heat producing tissues of the body (i.e. skeletal muscle) (50). In this regard an animal study demonstrated that the pharmacological agent had a greater effect in the presence of ingested carbohydrates compared to a lipid ingestion condition (51). Further research in this area is needed to confirm the potential to enhance the body's heat production, delay the onset of hypothermia during cold exposure, and the associated nutritional implications.

7.3 Hot ambient temperatures

In 1940 Lee (52) recognized that acute exposure to a hot environment caused a marked decrease in appetite, which was ameliorated with acclimatization. Adolph confirmed this heat related anorexia with military personnel in the field (53). Although earlier reviews point out inconsistent results in studies examining the effects of heat exposure on basal metabolic rate (34), there is insufficient evidence to demonstrate conclusively that a lower BMR is at the root of the anorexia. Neither is there any reason to believe that mechanical efficiency is improved in a hot environment. In fact, Consolazio et al. (54) demonstrated that in contrast to the decreased voluntary caloric intake, the caloric expenditure to perform a standardized exercise of a moderate intensity is increased. This has been attributed to the additional thermoregulatory metabolic demand associated with heat dissipation which is superimposed onto the caloric demand of the work. A specific task is therefore performed at a greater relative intensity, increasing the demand on carbohydrate metabolism as discussed earlier. This is manifested in greater carbohydrate oxidation with acute exercise in the heat (55,56).

When considering the physical demands on individual soldiers, body size should be considered. The smaller individual has a greater body surface area/mass ratio, and therefore a greater relative area for heat dissipation than in larger individuals (57). Also the extra heat associated with muscular work for a given task is a direct function of body weight.

The overriding nutritional concern in a hot environment is maintaining the body's hydration status. Marked impairments of endurance exercise performance are already noticeable with a fluid loss corresponding to about 3% of body weight (58), and increase commensurately with sweat loss.

8.0 Water balance

Although humans can survive for 40-50 days without the other nutrients described in this report, death usually occurs after about 10 - 15 days without water consumption. The physiological importance of water is demonstrated by the fact that it comprises between 40-70 percent of a human's total body weight (for review see ref. 59). This large range is due to the commensurately large variation among people in body weight consisting of fat, a tissue which contains little water. Thus for two people of similar weights but different body fat contents, the fatter individual will have less total body water.

In a comfortable ambient temperature normal water loss from an average sized sedentary male is about 2.6 litres per day, lost in varying proportions from the gastrointestinal tract, the respiratory tract, through the skin and from the

kidneys. This loss is balanced by intake of fluids (1.3 l), water in solid food (1 l), and water liberated during oxidation in cells (0.3 l). This state of water balance, euhydration, is normally maintained by humans with unlimited access to fluids under comfortable climatic conditions. The monitoring of body weight is the simplest method of checking whether water loss has exceeded water intake. A state of hypohydration is usually defined as a fluid loss amounting to greater than 2% of the normal body weight.

The amount of fluid intake required to maintain euhydration is a direct function of body size, the proportion of body mass consisting of fat, metabolic rate, and climatic conditions. Water loss can easily upset water balance because the human physiological systems are geared to prioritize the regulation of body temperature at the expense of the regulation of body water (60). Thus, increased physical exertion, ambient heat stress, or a combination of both has been reported to result in sweat losses which have been reported to be as high as over 2 l/h (58). In the absence of increased water intake, the body cannot compensate for such extreme fluid losses and the result has often been fatal in hot environments.

8.1 Survival water requirements

Minimum water requirements for survival were the subject of much study during WWII when there was a demand for recommendations for shipwrecked personnel or soldiers in the desert. A summary of British studies was written by Ladell (61) who concluded that during fasting, water intake of 0.8 - 0.9 l/day was necessary to prevent weight loss even in a temperate climate (Figure 1). He found the loss of 5% body weight after 24 h water deprivation was tolerable, but a 10% loss produced gross physical and mental deterioration. Gamble (62,63) reported that during a period of fasting for six days the minimal urine water requirement per day would be about 0.6 l, assuming 1.4 osmolar as the physiological maximum concentrating power of the kidney. Estimating insensible water loss at about 1 l would make a total obligatory expenditure of 1.6 l of water per day during fasting. With this assumption, he calculated that the minimal requirement for water intake during fasting under normal environmental conditions and near basal energy expenditure would be about 0.8 l. The remaining 0.8 l would become available from the fasting catabolism of body tissues.

8.2 Field applications

Brown et al. (64) calculated the expected survival durations for men on life rafts with restricted water supplies at various environmental temperatures and these are depicted in Figure 2. Fluid intake during military field trials over a wide range of ambient temperatures are summarized graphically in Figure 3, taken from Welch et al. (44). Recent American field trials confirm that their soldiers consume 2.7-4.3 l/day of fluids, including moisture in food, water added to rations, and drinking water (16,32,35). Table 3 is a guide to relate water requirements for a standard man to level of activity and thermal environment based on the observations of Buskirk (65) and Adolph (53). Practically, euhydration is almost ensured if fluid intake can account for sweat loss. Therefore, the reader may find it worthwhile to refer to Shapiro et al. (66), and the references contained therein, for equations to predict sweat loss for specific work loads, climates and clothing ensembles.

Table 3. Predicted fluid requirements at different air temperatures assuming relative humidity < 45%. Values are expressed as litres/day/man.

Activity	Daily Mean Air Temperature, °C					
	16	*21*	*27*	*32*	*38*	*43*
Hard work 8 h/day	3.5	5.0	7.5	10.5	15	
Same work as above 8 h/night	2.0	2.5	4.0	7.0	10.5	14.5
Resting in shade	1.75	2.0	3.0	5.5	8.75	12.5

Modified from ref. 53, page 121, figure 8-5.

Although sweat is hypotonic, the accumulated losses of potassium and sodium chloride can be severe with sweat rates of 8-10 litres/day. The salt losses are particularly marked during the initial period of head acclimatization, but sweat becomes more dilute with acclimatization (67). Conn and Johnson (68) stated that "...salt supplements are not needed and may actually be deleterious; that the average diet...affords adequate protection against salt depletion." More recent information suggests that potassium losses in sweat do not decrease with acclimatization to heat in contrast with sodium losses, and that attention should therefore be given to potassium nutritional content if personnel are expected to exercise at high sweat rates for several days (69). With regard to the maintenance of physical performance during activities causing high sweat rates and electrolyte losses, Pitts et al. (70) stated that "...the best performance of intermittent work is achieved by replacing water loss hour by hour and salt loss meal by meal;" there is no strong evidence to warrant changing this feeding strategy by, for example, adding electrolytes to canteen drinking water. The one exception may be while wearing impermeable protective clothing where solid food intake may be impossible, although a recent American evaluation of electrolyte supplemented fluid intake in such conditions showed no benefit compared to plain water (71).

8.3 Dehydration.

As discussed above, a water loss of greater than 2% of body weight indicates that the body is in a state of hypohydration, which, if allowed to reach 5 - 10% weight loss, can be associated with potential health hazards and marked physical performance impairments. Fluid deficits of 15-25% body weight are probably fatal, the former in hotter and the latter in cooler temperatures. The compensatory physiological adaptations which accompany long term exposure to heat stress or to altitude do not include protection from the debilitating and hazardous effects of dehydration. In other words, one cannot be physiologically acclimatized to hypohydration in a manner analogous to heat acclimatization. Although the once popular practise of restricting water intake in military personnel may familiarize them with the subjective feelings associated with dehydration, the high probability of real physiological damage associated with such "water discipline" makes it an unacceptable practise.

A direct quote is presented below from Stevenson (72) which summarizes some of the classical work of Adolph (53):

> *"Men in the desert, even when water is freely available, voluntarily dehydrate themselves between meals and make up their fluid deficits during meals. This voluntary dehydration*

may reach five percent of the body weight, sufficient to limit the physical performance of the man. Voluntary dehydration is reduced if meals are regular, if ample palatable water is available, and if there is sufficient leisure to drink it. Voluntary dehydration is increased by rapid sweating. It is therefore necessary under these conditions that men should be encouraged to drink more water than they want, especially during periods of prolonged activity. At the termination of dehydration men drink copiously for the first 15 or 20 minutes, and, if the deficit is not greater than about two per cent of their initial body weight, they replace it within this time. If the loss is greater than two per cent, water ingestion proceeds more slowly after 15 or 20 minutes of drinking, and a greater length of time is required for complete removal of the deficit. There may be adaptation to water lack, rendering voluntary dehydration more insidious as the day passes."

To counteract the potential for voluntary dehydration it is recommended that fluid losses be replaced by drinking volumes of 0.1 - 0.2 l several times per hour during prolonged exposure to heat stress.

9.0 General Recommendations

Recognizing the potentially detrimental effects of low muscle glycogen levels on physical performance, it is recommended that standard daily combat rations contain > 400 g CHO.

Certain operational scenarios may require deviations from accepted nutritional guidelines, such as caloric restriction. Such deviations should not be extended beyond 14 days until research is carried out to document the long term health implications. In this regard it is specifically recommended that research be carried out to evaluate the effects of ingesting calorie dense diets (>60% fat energy) for several weeks, the time course of adaptation (if any), and the implications for physical and mental performance.

In light of the paucity of information, research should be directed to investigate the nutritional implications of wearing protective clothing for water and salt balance and associated thermoregulation during heat stress.

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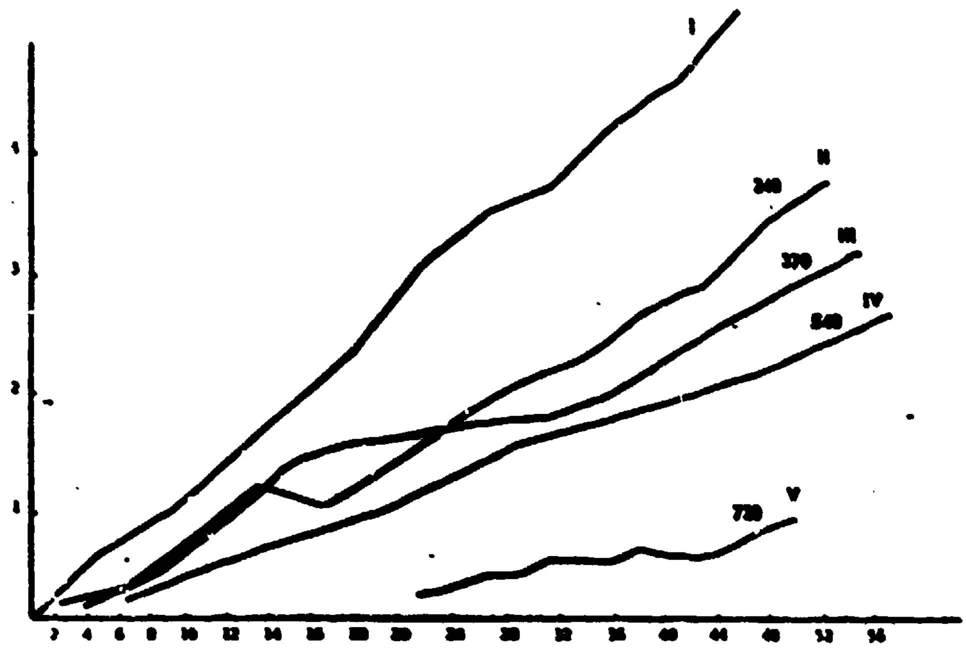
Figure 1. A comparison of the percent weight loss over time while consuming varying volumes of water (from ref. 61).



Abscissae : time in hours
Ordinates : % weight-loss
I: 2 subjects ([illegible] & [illegible]), [illegible] experiments; day 2, 3
II: 1 subject ([illegible]), [illegible] experiment; day 2, 4
III: 2 subjects ([illegible] & [illegible]), 1 experiment; day 2, 3
IV: 15 subjects (Royal Naval Hospital, [illegible]); day 2, 3
V: 1 subject ([illegible]), 1 experiment; day 4
Arabic numerals on the graph show water-intakes in cm^3 per day

Figure 2. Relation between air temperature and time required to reach limiting weight deficits on various initial water supplies (from ref. 64).

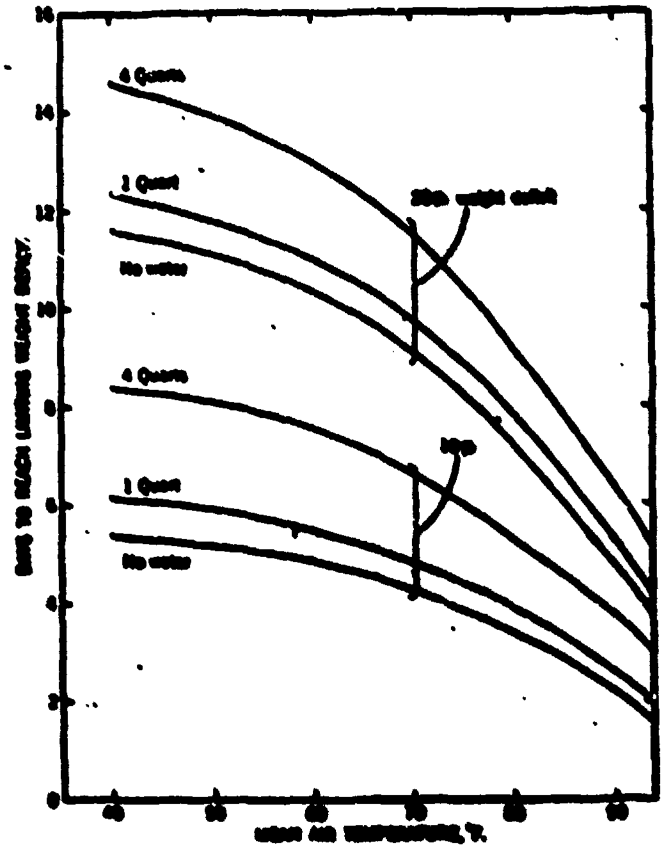
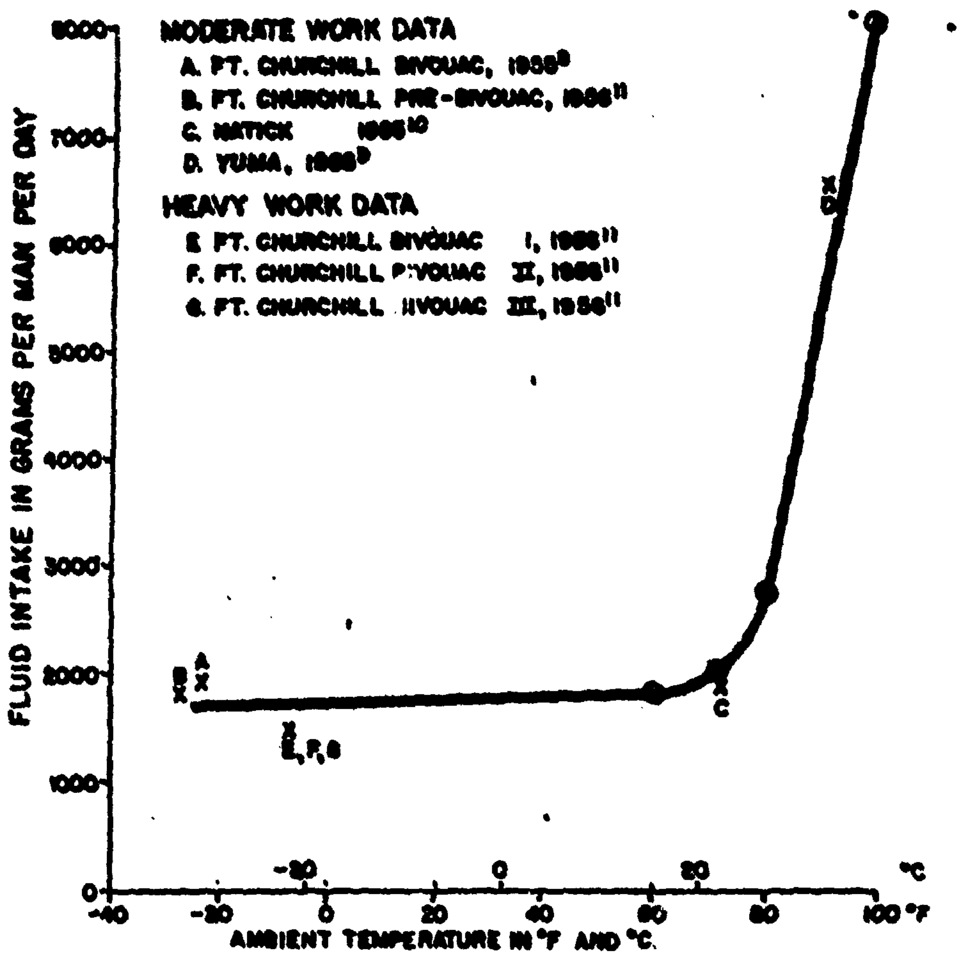


Figure 3. Fluid intake during military field trials (from ref. 44).



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This report is a review of research findings concerning nutritional aspects of physical performance with direct relevance to the operational requirements of military personnel. Among the macronutrients providing fuel to working muscle, only carbohydrates are relatively limited in availability. Since muscle depends on carbohydrates as an energy store for high intensity exercise performance, depletion of these stores have detrimental effects on exercise performance. In contrast, there is no consistent evidence that physical exercise performance would be enhanced by the addition of micronutrients to standard rations. Calorie restriction may be a necessity when a lightweight foodpack would be beneficial in order to save weight and volume requirements for highly mobile units. If dehydration, ketosis and hypoglycemia can be avoided, weight loss of up to about 10% will not cause drastic performance impairments. The environmental stress of heat or altitude causes an anorexia which can result in insufficient energy and/or carbohydrate intake to maintain optimal physical performance. Cold environments are usually associated with an increased energy consumption, probably because of the increased caloric cost of working in protective clothing and with specialized equipment. The implications of most environmental stresses are that the relative physiological demands of a given task are increased. In all likelihood the energy cost and the dependence on carbohydrates for that energy are also increased.

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